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RADIAL GROWTH ASSESSMENT OF WESTERN SPRUCE BUDWORM INFESTED DOUGLAS-FIR TREES ON THE CARSON NATIONAL FOREST, NEW MEXICO

Thomas W. Swetnam

RADIAL GROWTH ASSESSMENT

OF

WESTERN SPRUCE BUDWORM INFESTED DOUGLAS-FIR TREES

ON THE

CARSON NATIONAL FOREST, NEW MEXICO

A Report Prepared by:

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ABSTRACT

Growth of western spruce budworm (WSBW) infested Douglas-fir (Pseudotsugae menziesii) forests on the Carson National Forest, New Mexico, was assessed through dendrochronological analysis of increment cores extracted at breast height. Comparisons of indexed and filtered host and non-host (ponderosa pine [Pinus ponderosa]), tree-ring chronologies revealed that host tree growth was reduced during past and present WSBW outbreaks. The non-host chronologies were used to remove the non-WSBW growth effects from the host chronologies, and the corrected host tree growth indices were then used to assess growth loss during known outbreak periods. Maximum growth loss during one year was generally greater than 50 percent. The average growth loss for five year periods during outbreaks was approximately 30 to 40 percent, and the maximum growth loss between two years during an outbreak was usually more than 50 percent.

INTRODUCTION

Western spruce budworms, Choristoneura occidentalis Freeman, have repeatedly defoliated conifer trees throughout forested areas of North America. Mixed conifer and spruce-fir forests of the southwestern United States have not been immune to the recurrent damaging effects of this insect. The most recent infestation on the Carson National Forest, New Mexico, has resulted in defoliation of more than 100,000 acres (40,471 ha) of Douglas-fir (Pseudotsugae menziesii), true firs (Abies spp.), and spruce Picea spp.) (Stein 1981).

In 1978 a damage assessment project was undertaken to measure the extent of defoliation and amounts of topkill, mortality, and growth loss. This report describes preliminary results of a study designed to assess the effects of western spruce budworm (WSBW) on radial growth of surviving trees. The two primary objectives of this study were to (1) determine if current and previous periods of WSBW defoliations could be detected in Douglas-fir tree-ring series, and (2) to measure any observable growth loss.

Tree-rings have been used to measure the effects of WSBW activity by Blais (1965) and Mott and others (1957) in balsam fir forests (Abies balsamea) in the eastern United States, and by Brubaker and Greene (1978) and Carlson and McCaughey (1982) in Douglas-fir forests in the west. This study is the first effort to assess WSBW activity in southwestern mixed conifer forests using dendrochronology.

The objectives of this study have been effectively met, however, additional collections and analyses would help to verify the findings. Furthermore, the success of the methods employed in this study indicate that other growth assessment investigations may also provide useful information. A description of future work that would help to improve and expand growth loss estimates is included at the end of this report.

Records of WSBW on the Carson National Forest

Records of WSBW occurrence in the Southwestern Region (R-3) were summarized by Lessard (1975). Additional information on the extent and timing of infestations was obtained from Annual Insect Reports prepared by Regional Office personnel from 1924 to 1956, and from reports and documents filed by forest entomologists and other officials following area inspections (files temporarily located at Laboratory of Tree-Ring Research).

The records indicate that there have been at least four major outbreaks of WSBW on the Carson National Forest since the 1920's. WSBW activity was first recorded in Region 3 in 1922 on the western division of the Carson. This infestation apparently remained on the western side of the Rio Grande. WSBW was first recorded on the eastern division of the Carson in 1940, and was reported as epidemic in 1944 but not so heavy in 1945. WSBW populations declined after 1946, but remained present in many areas, causing only slight damage during the late 1940's.

Populations increased again throughout the mixed conifer types in northern New Mexico in the late 1950's. This outbreak reached a high of approximately 1 million acres infested in 1961, declining somewhat in 1963. This infestation persisted through the mid-1960's with isolated and smaller infested areas appearing in the late 1960's and early 1970's.

The most recent widespread outbreak of WSBW was first noticed on the Taos Indian Reservation in 1975, with infested areas gradually increasing in size since that time. Large areas have sustained light to severe defoliation on both the eastern and western divisions of the Carson, as well as areas on the Santa Fe and Cibola National Forests (Stein 1981).

METHODS

Collections

In July 1982 increment core collections were obtained from five different study areas on the Taos, Questa, and Tres Piedras Ranger Districts. Increment cores were taken from host trees and non-host trees so that growth comparisons could be made. The sample host trees were all Douglas-fir and the non-host trees were all ponderosa pine (Pinus ponderosa), with the exception of one piñon (Pinus edulis) collection from Cabresto Canyon on the Questa Ranger District. Each of the host and non-host collections consisted of two increment cores from each of 15 to 30 trees. Table 1 lists the number of trees used in the analyses, and other characteristics of the collection sites. The collection sites were located within and around one-acre study blocks that were established in 1978 and 1979 for long term monitoring of WSBW activity (Stein 1981).

Laboratory Preparations

Increment cores were mounted in wooden holders and sanded. The annual rings of all samples were crossdated by the skeleton plot technique (Stokes and Smiley 1968) to assure that accurate calendar year dates of formation were assigned to individual rings. This is an essential step in tree-ring analysis because locally absent rings and false rings are not uncommon in conifer trees, especially if the trees have survived stressful conditions such as drought or insect defoliations. The original dating of each core was checked by a second dendrochronologist.

The crossdated annual rings of each specimen were measured on a sliding stage micrometer interfaced with an Apple II+ microcomputer (Robinson and Evans 1980). Measurements were to within 0.01 millimeter. Original measurements were checked for accuracy by remeasuring approximately one fifth of the rings on each core. A statistical test was then

Table 1. Number of trees sampled and characteristics of collection sites. Species abreviations are Pseudotsugae menziesii (PSME), Pinus ponderosa (PIPO), Pinus edulis (PIED), Abies concolor (ABCO).

	Capulin Canyon (CPN)	Garcia Park (GAR)	Cabresto Canyon (CAB)	Osha Mountain (OSH)	Burned Mountain (BRN)
No. of Trees[1]					
PSME	17	17	10	11	19
PIPO	12	18		20	
PIED			18		
Block No.s[2]					
	6	7	9	16	17
Species Composition[3] (%)					
PSME	44	83	70	12	82
ABCO	30	2	3	17	7
PIPO	26	15	27	71	11
Elevation					
	9,600 ft. (2,926 m)	8,800 ft. (2,682 m)	8,600 ft. (2,438 m)	9,600 ft. (2,926 m)	9,700 ft. (2,956 m)

[1]Number of trees at CPN, GAR, and CAB are the number used in the analyses described in this report. Number of trees at OSH and BRN are number sampled but have not been analyzed yet.

[2]Trees were sampled within and around one-acre study blocks established in 1978 and 1979. Descriptions and maps of study blocks are included in Stein (1981).

[3]Data from Stein (1981).

applied to determine whether the original measurements were acceptable or required remeasurement (Burns 1979).

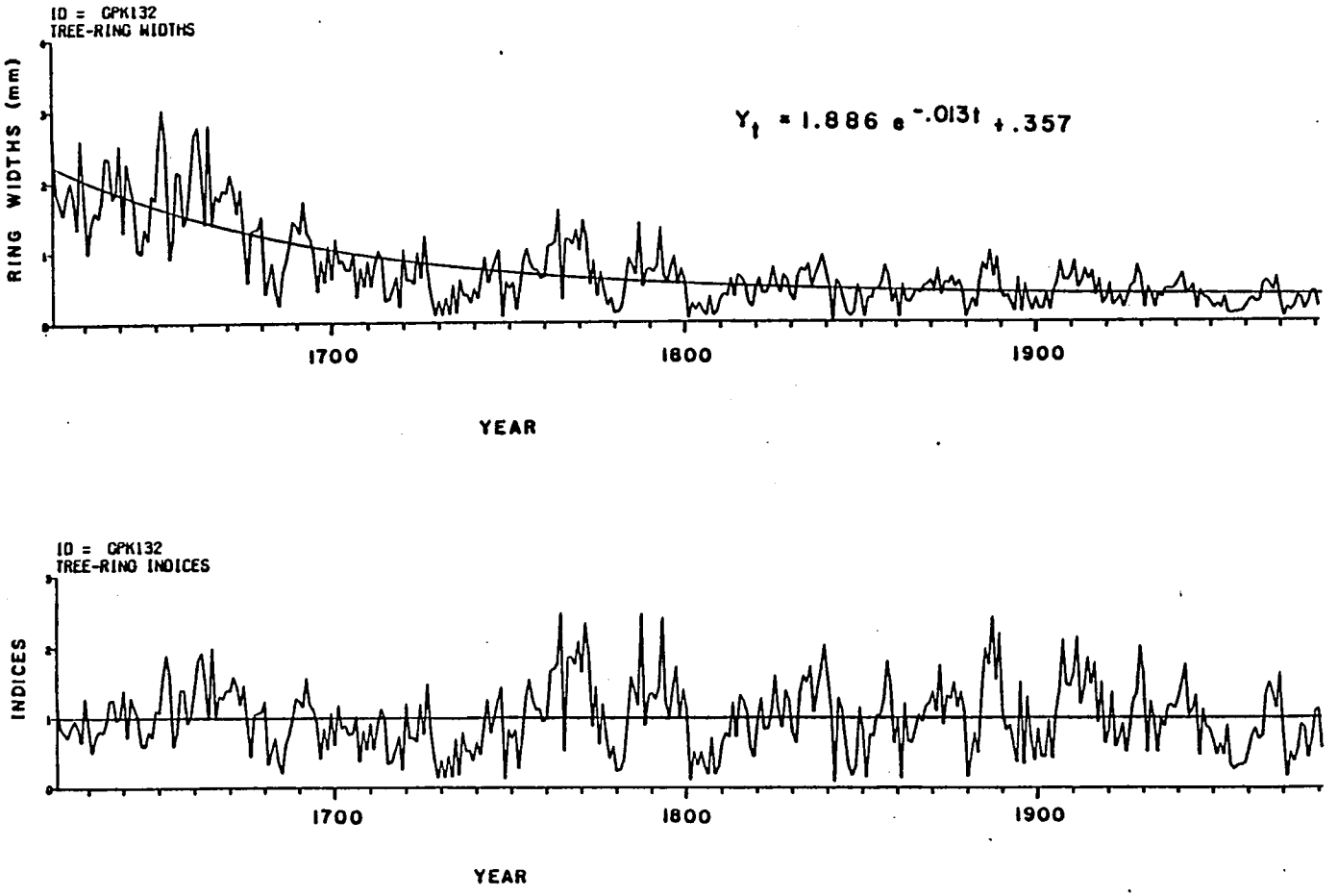
Standardization and Computer Analyses

Three paired sets of host and non-host ring-width measurements have been processed through numerical transformations and analyses that are described in this section. These tree-ring samples were collected from the eastern division of the Carson National Forest at Capulin Canyon (CPN) and Garcia Park (GAR) on the Taos Ranger District, and from Cabresto Canyon (CAB) on the Questa Ranger District.

All ring-width measurements were plotted (fig. 1) so that growth trends could be observed. Most of the specimens displayed the typical "biological growth trend", which is characterized by large ring widths and high variability near the pith, and smaller rings and lower variability near the bark. This trend is primarily due to the aging of the tree and increasing circumference of the tree bole (Fritts 1976).

In order to facilitate the averaging together of many tree-ring series of different lengths, and to make the variance of the inner portion of each series equivalent to the outer portions, it was necessary to standardize the ring-width measurements into growth index values (Fritts 1976, Graybill et al. 1982). This was accomplished with a program called INDEX (Graybill 1979), which effectively removes growth trends from ring-width series. The computer procedures involved the fitting of a negative exponential curve, straight line of negative slope, or horizontal line, to each ring-width series, depending on the general shape of the biological growth trend (fig. 1). Each ring-width value was then divided by the corresponding value of the fitted line at that point.

Figure 1. Plots of ring widths and growth indices of a ponderosa pine sampled at Garcia Park. The negative exponential growth curve that was fit to the ring-width series by the program INDEX is shown at the top. Division of each ring-width value by the corresponding value of the fitted line produces the index values shown at the bottom. The horizontal line is the approximate mean of the series.



The fitted curve or line can be considered the expected growth of the tree if no environmental influences, such as climatic change or insect defoliations, were affecting the tree. The result of standardization is a set of growth indices (fig. 1) that vary about a mean of approximately 1.0 (the expected growth for any given year).

Indexed tree-ring series are very useful because they can be averaged together to form summary chronologies for a tree and for a site. Ring-width series of different lengths cannot be meaningfully averaged because the large ring widths on the inner portion of shorter series would create a rise in the averaged series and would also create a higher variance at that point. Index series are also convenient because they provide a standard reference to expected tree growth, which is the mean of the series.

The summing or averaging of the tree-ring series at each site was accomplished with the program SUMAC (Graybill 1979). This program averages the two series from each tree into a tree summary, and then as a final step, averages all the tree summaries into a final summary for the site. SUMAC also computes an analysis of variance and correlation for a period of years common to all series used in the summation.

All of the individual tree summaries, final summaries for the host trees, and final summaries of the non-host trees were processed through two other transformations. The first was a filtering procedure that emphasized long term changes in the indexed tree-ring series for graphical comparison of host and non-host tree growth. Since WSBW outbreaks typically build gradually and may last 10 or more years (Lessard 1975, Carlson, et al. 1983), the effects on tree growth are probably observable over relatively long periods of time. The filtering procedure effectively removes the variation occurring at shorter intervals, which tends to obscure the comparisons of host and non-host series.

Figure 2 is a plot of the Capulin Canyon Douglas-fir final summary with the low pass filtered series overlaid on the index series. The low pass filter smoothes the index series by multiplying each index value and surrounding values by a set of symmetrically weighted values (Mitchell, et al. 1965).

The second transformation was a correction of the host tree series by subtracting non-host series, which were first scaled to the same variance as the host tree series. The corrected host tree series retain the variations in tree growth that were not in common between the host and non-host series. Thus, WSBW effects on the host trees were presumably retained in the corrected index series, while the effects of other environmental influences to which both host and non-host were responding (eg., climate), were removed. This technique was first developed by Nash, Fritts and Stokes (1975) for a study of the effects of copper smelter pollutants on tree growth in central Arizona. The computer program TRMCLM utilizes the following equations to derive corrected indices:

$$PRI = \frac{SDEV(H)}{SDEV(NH)} \left((INDEX(NH) - MEAN(NH) \right)$$

$$CI = INDEX(H) - PRI$$

PRI is the predicted residual index value for each year of the non-host series, SDEV(H) and SDEV(NH) are the standard deviations for the host and non-host series, INDEX(NH) and INDEX(H) are each index value of the host and non-host series respectively, MEAN(NH) is the mean of the non-host series (about 1.0), and CI is the corrected index value for each year of the host tree.

In this study, the use of the TRMCLM technique was based on two assumptions. First, the host and non-host trees were assumed to be

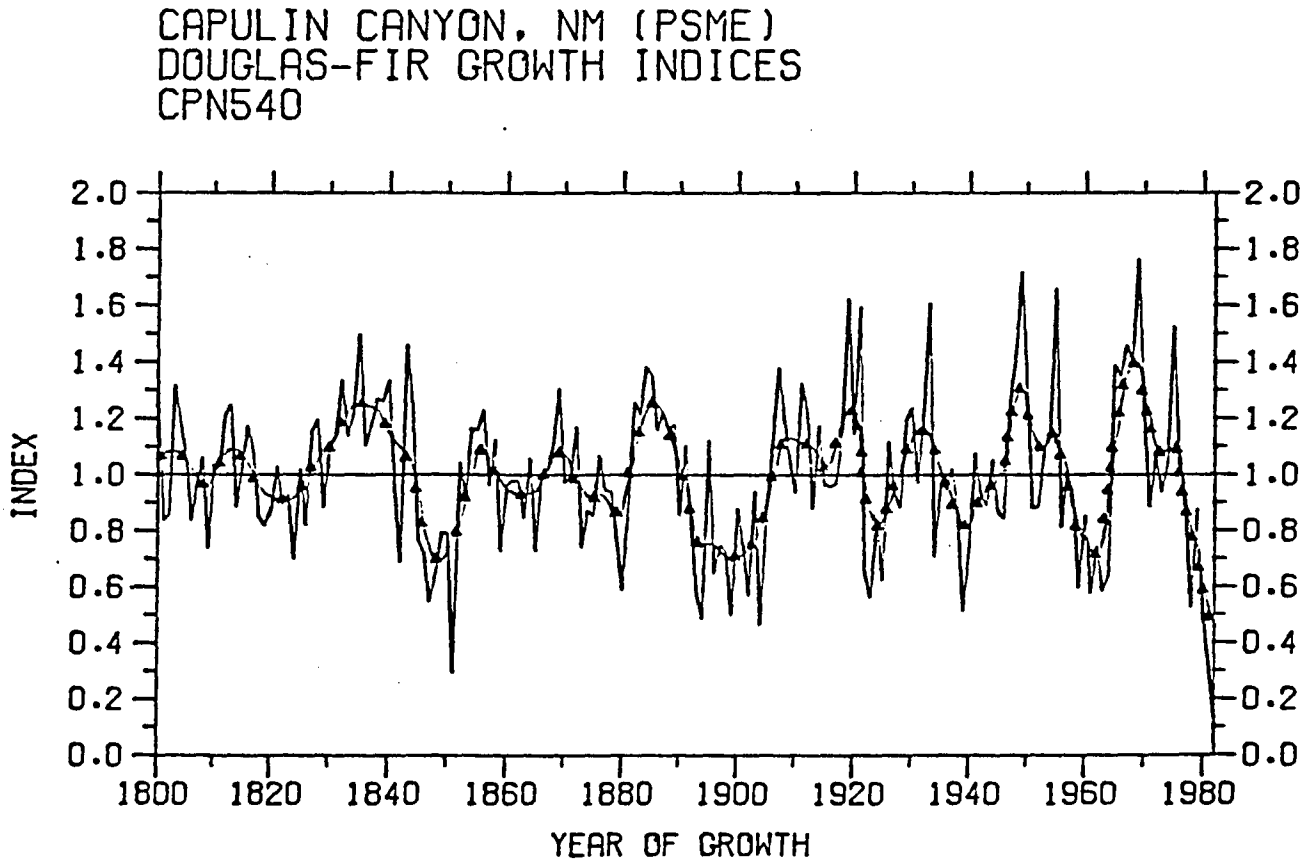


Figure 2. Plot of Douglas-fir final summary indices (line) and low pass filter values (triangles). The low pass filter preserves most of the variance with wavelengths greater than approximately 8 years.

responding in a similar manner to environmental influences other than WSBW. This was probably a reasonable assumption since most of the variation in tree growth, especially in the Southwest, is due to variation in climate (Fritts 1976), and Douglas-fir and ponderosa pine at this particular location probably have a fairly similar response to climate (H. C. Fritts, pers. comm.). Response of pinon and Douglas-fir at the CAB site to climate may have been significantly different. This problem will be discussed in the results section.

Second, since WSBW does not ordinarily feed on ponderosa pine or piñon foliage, the non-host trees were assumed to be unaffected by WSBW. However, other researchers have found that non-host trees growing within the same stand as host trees may actually grow more rapidly than expected because of the reduced competition from nearby defoliated host trees (Carlson and McCaughey 1982). Thus, if the non-host trees were affected in this manner then the corrected indices would overestimate growth losses due to WSBW.

The Douglas-fir and ponderosa pine were mixed in the same stand at the CPN site, and the ponderosa pine sampled at GAR were in a stand that was close to, but separate from, the Douglas-fir. The piñon trees sampled at CAB were completely separate from the sampled Douglas-fir. Therefore, the effects of WSBW at CPN may be overestimated by the corrected indices, but this is probably not a problem with the GAR and CAB corrected indices.

It is also possible that the corrected indices underestimate growth loss in the host trees. Researchers have found that defoliated trees sustain the most severe growth loss within the crown portion of the tree stem (Mott et al. 1957). Since all of the measurements used in this study were from the base of the sample trees, the growth loss estimates, at least at the GAR site, are probably conservative.

Measures of Growth Loss

The final step in the analysis was the quantification of growth loss that was identified by the filtered series comparisons, and the corrected host tree indices. Three different measures that were first used by Brubaker and Greene (1979) were utilized in this study, and are presented in histogram form in the results section:

1. Maximum Growth Loss for One Year. This was the largest growth loss for a single year during each of the known periods of infestation. It was computed by subtracting the minimum index value during an infestation from the expected growth value (1.0), and then multiplying by 100 to give growth loss as a percent of expected growth.
2. Five Year Growth Loss. This was the average growth loss for a five year period, centered on the minimum index year during an infestation. It was computed by summing the index values for the five year period, subtracting the sum from 5.0 (the sum of expected growth indices during that period), dividing by 5.0, and then multiplying by 100 to give growth loss as a percent of expected growth.
3. Maximum Rate of Growth Reduction. This was the largest growth loss between two years during an infestation period. It was computed by finding the largest difference between the index values for two consecutive years and then multiplying the difference by 100 to give growth loss as a percent of expected growth.

RESULTS AND DISCUSSION

Comparisons of Filtered Growth Values

Graphical comparisons of the host and non-host tree-ring series revealed that growth loss was observable during three of the past WSBW infestations on the Carson. Comparisons of the three sites that have been

processed through standardization and filtering are shown in figure 3. The minimum filtered index values during periods of known WSBW infestation are indicated with arrows. It can be seen that Douglas-fir growth is noticeably less than ponderosa pine growth in the CPN and GAR comparisons, while the CAB comparison is not conclusive.

Although the differences between Douglas-fir and ponderosa pine growth in the CPN and GAR series are not particularly striking, it should be noted that these are comparisons of the final summaries, in which all tree summaries from each site are included. Comparisons of individual Douglas-fir tree summaries with the corresponding non-host final summary from the same site indicate that the effects of WSBW vary from one tree to another. Some trees apparently suffered no growth loss during some infestations, while others were markedly affected by several infestations. Thus, when all tree summaries are averaged into the final summary, the growth effects of the infestation are muted.

Figures 4 and 5 show comparisons of selected individual Douglas-fir tree summaries with the corresponding ponderosa pine final summaries. The major infestation in the mid-1940's appears in almost all of the Douglas-fir trees sampled at CPN and GAR, while the early-1960's and present infestations are represented by fewer trees.

Although the differences in growth between the non-host and host series are generally greatest during the known periods of infestation, there are other portions of the series where there are either positive or negative differences. For instance, during the 1890's Douglas-fir growth at GAR was below ponderosa pine growth in most of the sampled trees. This difference may also have been caused by WSBW, however, since there is no independent documentation of an infestation during this period, the actual

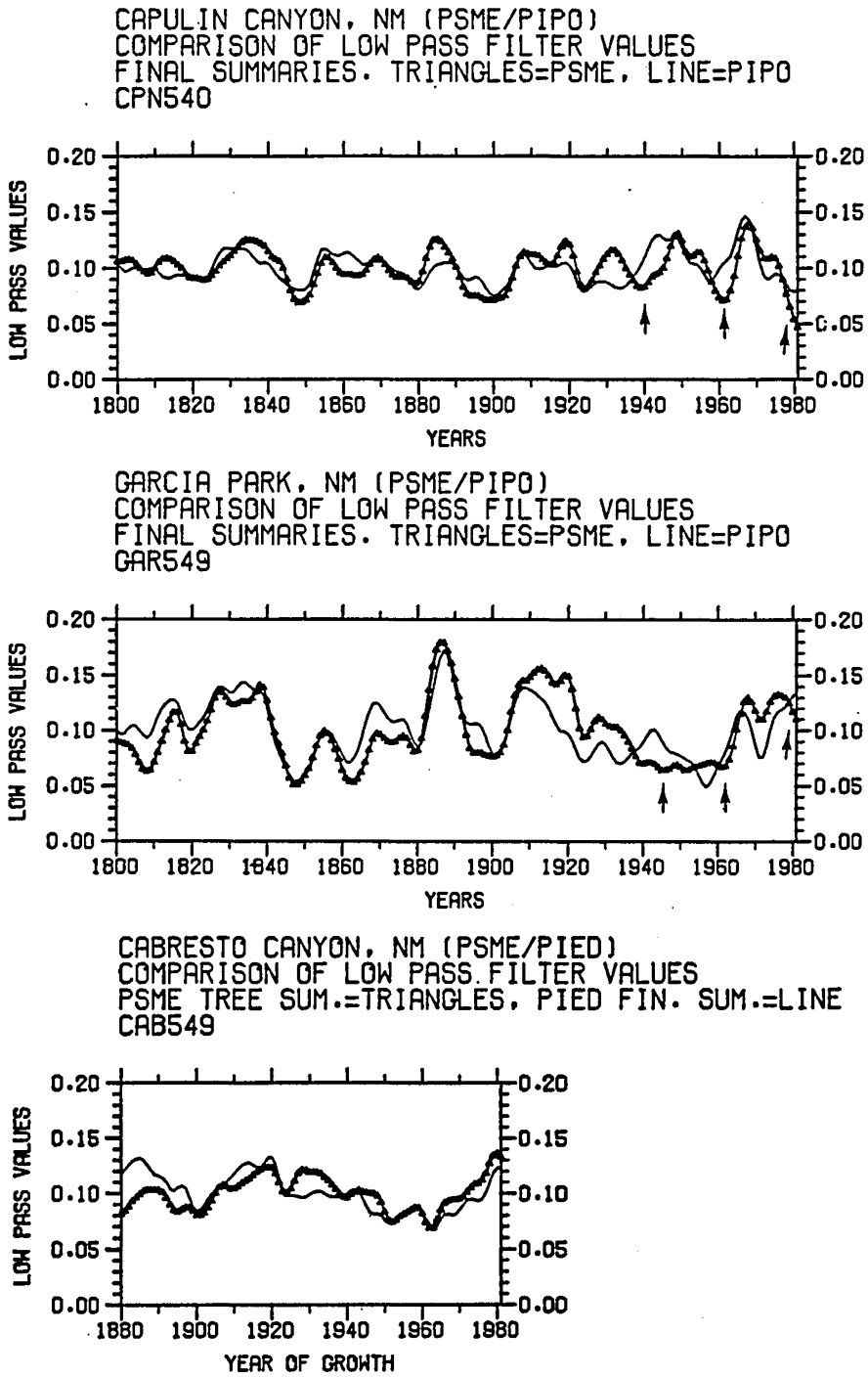


Figure 3. Plots of low pass filtered values of Douglas-fir and ponderosa pine final summaries. The lowest Douglas-fir growth values during known infestation periods are shown with arrows.

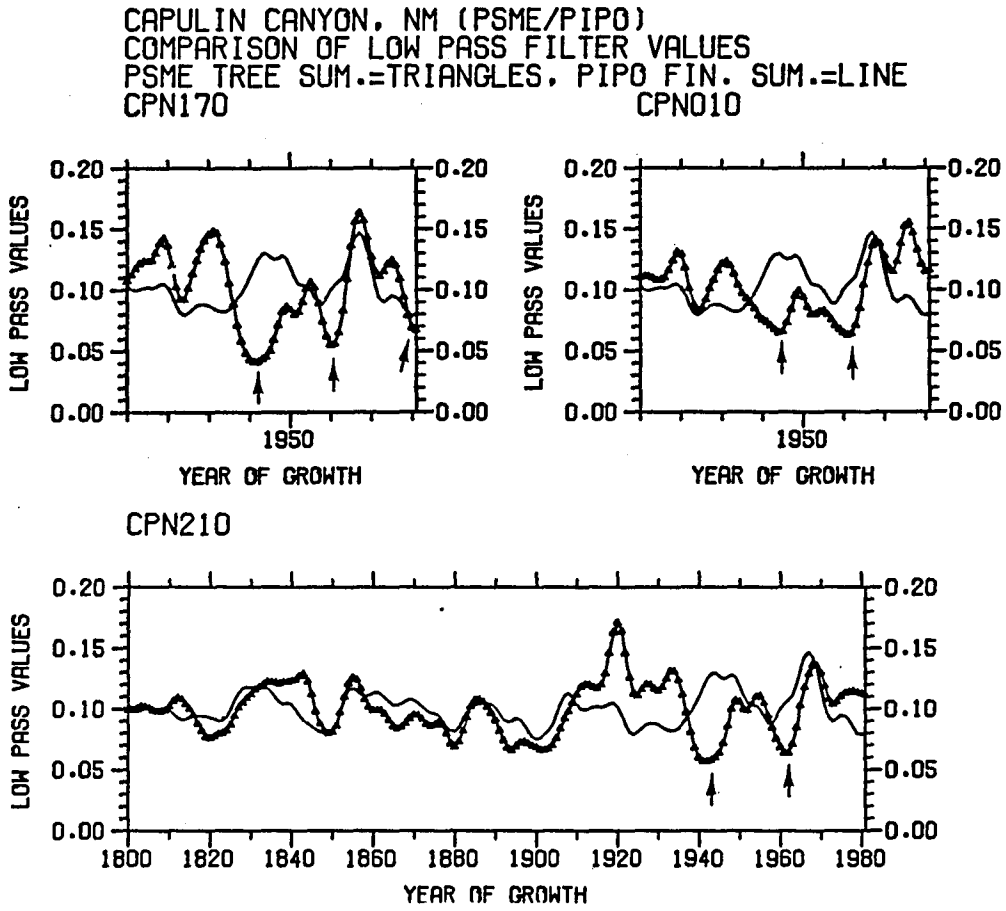


Figure 4. Plots of low pass filtered values of selected Douglas-fir trees and the ponderosa pine final summary from Capulin Canyon. Periods of lowest Douglas-fir growth during known infestations are shown with arrows.

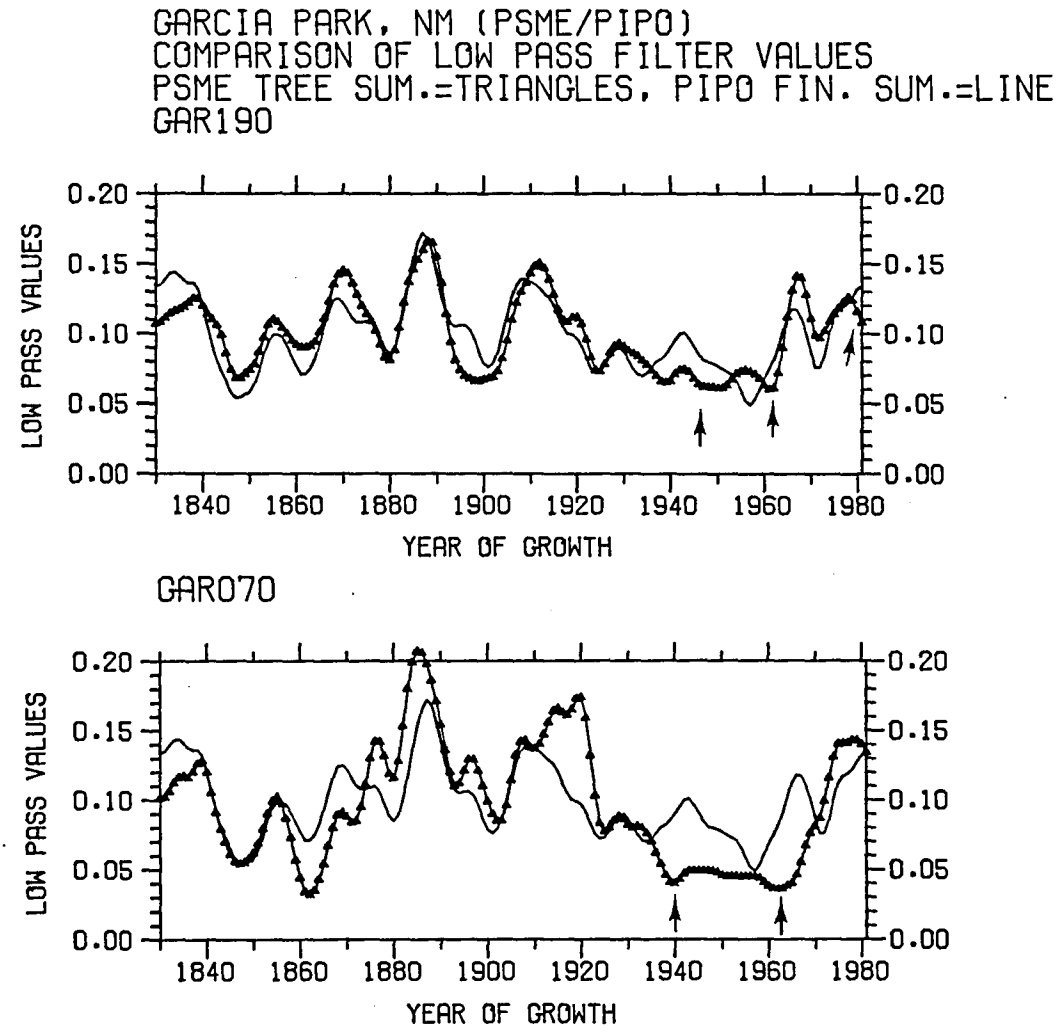


Figure 5. Plots of low pass filtered values of selected Douglas-fir trees and the ponderosa pine final summary from Garcia Park. Periods of low Douglas-fir growth during known infestations are shown with arrows.

cause cannot be determined at this time.

The individual tree summary for CPN210 (fig. 4) represents a case where Douglas-fir growth was significantly greater than ponderosa pine in the late 1930's. This rise in Douglas-fir growth with no corresponding rise in ponderosa pine growth was noted in several other trees. The cause of this difference is not known.

Despite these instances of unexplained differences in growth between the host and non-host trees, the comparisons show a general similarity in overall growth trends. Furthermore, the differences observed between host and non-host tree-ring series during the known infestation periods are usually the greatest differences observed in the comparisons.

As previously noted, the comparison of the final series for the CAB site showed no definite periods of growth loss coinciding with known periods of defoliation. Comparisons of the individual Douglas-fir tree summaries with the final piñon chronology for this site showed that some trees sustained growth loss during the present infestation and earlier infestations. However, the lack of consistent growth loss among a majority of the sampled trees for any of the known periods of infestation seems to indicate that either this particular site has not experienced the extent of defoliation that has occurred on the CPN and GAR sites have, or for some other reason many of the trees were able to continue growing at nearly the same rate as the piñon trees.

One possible explanation may be that since the CAB trees were, on the average, younger than trees at CPN and GAR, they may have been more able to withstand the effects of defoliation. Another possible explanation may be that the piñon and Douglas-fir trees sampled at this site were too dissimilar in response to climate or other environmental influences,

so that consistent differences between the series are obscured. In contrast to the CPN and GAR host and non-host collections, the CAB Douglas-fir and piñon collections were from areas separated by several miles, and the trees at the two sites were growing on different aspects, slopes, and soils. Additional collections of non-host trees closer to the host trees at CAB may help to resolve problems with the growth comparison at this site.

Corrected Host Tree Series

All of the individual tree summaries and final summaries from the CPN, GAR, and CAB collections were processed through the TRMCLM program. Figure 6 shows plots of corrected indices of the final summaries for the period 1800-1981 for CPN and GAR, and 1870-1981 for CAB. Seventeen trees were included in the CPN and GAR final summaries after approximately 1900, and nine trees were included in the CAB final summary after 1910. At least five trees comprise the earliest portions of all three final summaries.

Growth loss during each of the known periods of infestation is visible in the CPN and GAR series, whereas similar periods of growth loss are not apparent in the CAB series. The corrected index values for CPN tree growth during the 1940's, 1960's and 1979 to 1981 were the lowest values for the entire 1800-1981 chronology. The most recent infestation was just beginning to be recorded in the late 1970's, and the recovery period had not begun as of 1981.

The corrected indices for GAR are also low during the known periods of infestation, and the values for 1979-1981 were the lowest recorded for the entire 1800-1981 period. However, other periods during the chronology also have low values, such as a period during the late 1890's, that was also visible in the filtered comparisons (fig. 3). The low corrected index values observed during known infestations appear to be more consistent among

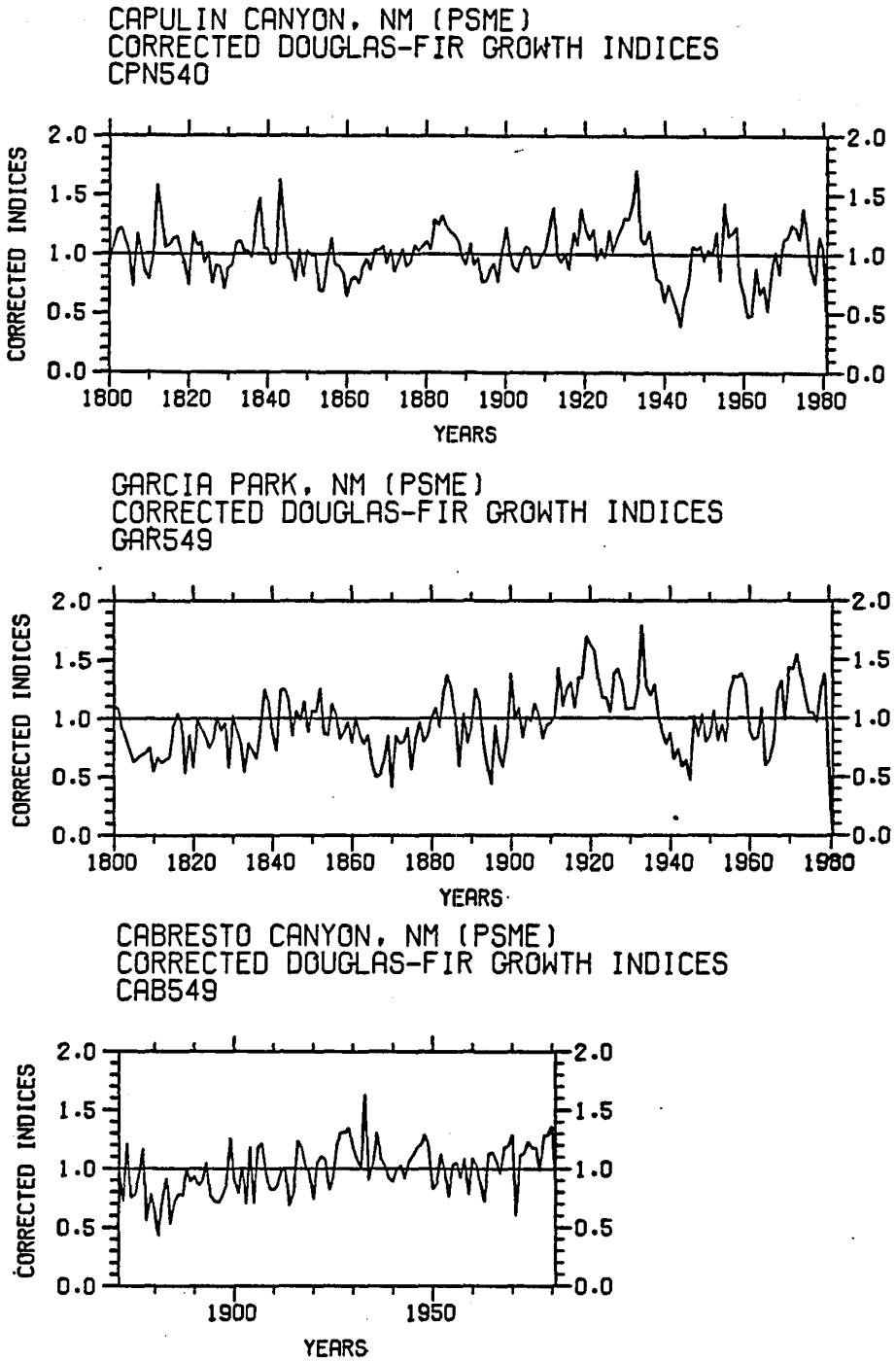


Figure 6. Plots of corrected Douglas-fir final summaries.

the sample trees than other periods of low growth.

The extended periods of low growth visible in the CPN series during known periods of WSBW outbreaks, with no comparable periods of low growth in earlier portions of the series, suggests that severe growth loss due to WSBW is a twentieth century phenomenon. This observation is less clear at the GAR site because of observed periods of low growth in earlier periods of the series. However, the growth loss during the known outbreaks at GAR also appear to be the most consistent and long lasting periods of low growth for the entire 1800-1981 period.

Measures of Growth Loss

The CAB corrected indices did not consistently show periods of growth loss that can be attributed to WSBW, so no measures of growth loss were compiled for the sample trees from this site. Measures of growth loss were compiled for each corrected index tree summary from the CPN and GAR sites, and are displayed as histograms in figures 7 and 8. The dates of infestation are approximate and are based on Forest Service records. Median values are shown on each histogram.

The maximum growth loss for one year during each of the known infestation periods was generally greater than 50 percent. In other words, tree growth was reduced to at least half of the expected growth during the lowest growth year.

The five year growth loss was at least 30 to 40 percent for most trees, but this measurement was more variable among the trees than the measurement of maximum growth loss for one year. The five year growth loss measurements for the most recent infestation (1974 to present) were not centered on the minimum corrected index values because these values were usually the last ring of the series (1981), so the five year periods included the years

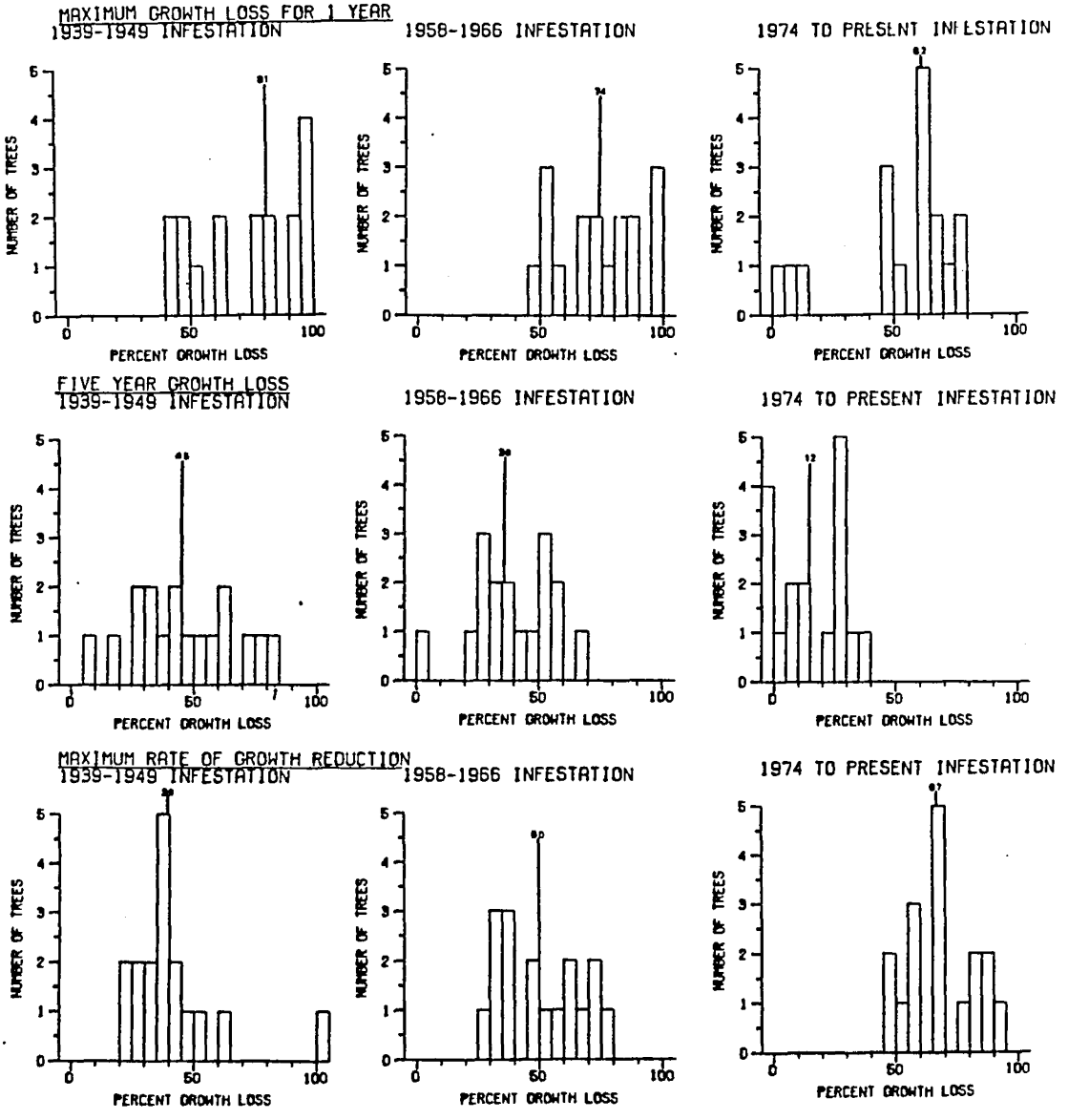


Figure 7. Histograms of growth loss measurements from Capulin Canyon. The top row is the maximum growth loss for 1 year during each known infestation period. The middle row is the average five year growth loss for each period, and the bottom row is the maximum rate of growth reduction for each period. The median growth loss values are indicated with a verticle line on each histogram.

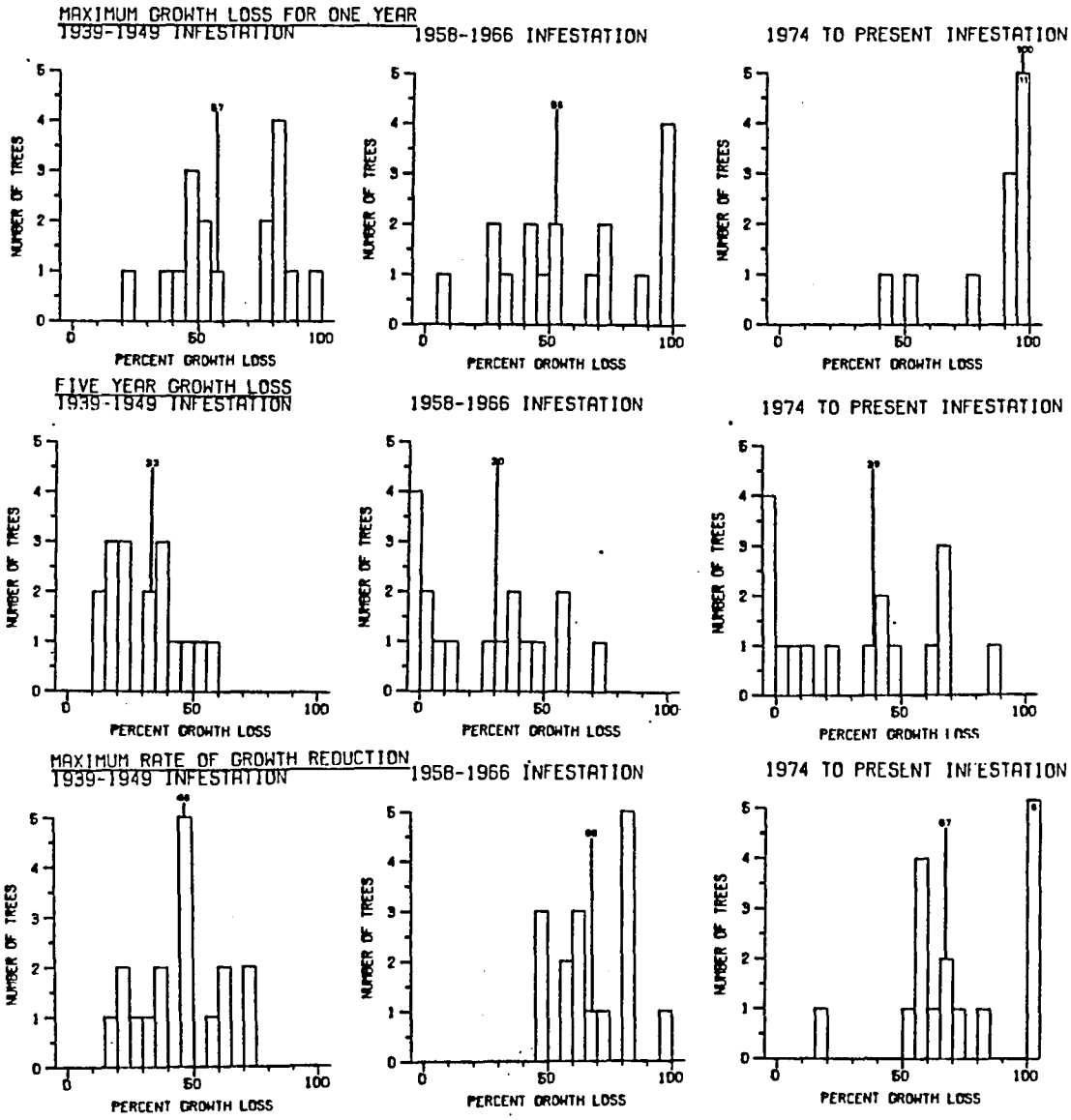


Figure 8. Histograms of growth loss measurements from Garcia Park. The top row is the maximum growth loss for 1 year during each known infestation period. The middle row is the average five year growth loss for each period, and the bottom row is the maximum rate of growth reduction for each period. The median growth loss values are indicated with a verticle line on each histogram.

1977 to 1981. Since the trees had not begun recovering by 1981, this measurement is a conservative estimate of growth loss for this outbreak.

The maximum rates of growth reduction were generally greater than 50 percent for most trees and were as high as 100 percent for some trees. It was also noted that the maximum reduction in growth from one year to the next usually occurred near the beginning of the infestation period.

SUMMARY

The comparisons of filtered host and non-host tree-ring series clearly identified three periods of low growth in the CPN and GAR host trees that corresponded with known periods of WSBW outbreaks. This evidence provided a basis for further analyses that utilized the non-host series to remove growth effects other than WSBW from the host series. The corrected host tree indices were then used to measure growth loss during identified WSBW outbreak periods.

The maximum growth loss during a single year of the outbreaks was usually greater than 50 percent. Average growth loss during five year periods was approximately 30 to 40 percent. The maximum growth loss from one year to the next was generally greater than 50 percent and was as high as 100 percent.

The measures of growth loss at the CPN site may overestimate growth loss because the ponderosa pine trees may have benefitted from defoliation of the host trees. This effect has probably not occurred at the GAR and CAB sites because the host and non-host trees are separate at these sites.

In general, the measures of growth loss are probably conservative, at least at the GAR site, because all of the measurements were from increment cores sampled at the bole of the trees. Other researchers have found

that maximum growth loss in WSBW infested trees usually occurs within the crown portion of the stem (Mott et al. 1957).

Results of comparisons of host and non-host tree-ring series at the CAB site were inconclusive. A few of the trees exhibited growth loss during present and past infestations, but most did not. Additional sampling at this site might help to determine the reasons for these results.

FUTURE WORK

We feel that additional sampling of infested trees and analysis of their tree-ring series would help to verify the findings of this study and answer other questions regarding WSBW effects on tree growth. The number of samples included in the analysis of each site is relatively small and additional sampling in these areas would probably improve the growth loss estimates.

Additional work that we would like to undertake, depending on continuous funding, includes the following:

1. The processing and analyses of increment core samples obtained in 1982 from Osha Mountain on the Taos Ranger District and Burned Mountain on the Tres Piedras Ranger District.
2. The collection of increment cores and development of a chronology for non-host trees from the Burned Mountain area.
3. The improvement of growth loss estimates for the CPN, GAR, and CAB sites by the collection and analysis of additional increment core samples.
4. The identification of possible differences in growth loss between age classes of trees or site classes.
5. The investigation of the effects of past spraying programs on radial growth of WSBW infested trees.

We plan on developing a detailed proposal describing these investigations in the near future.

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